TRITON BLUSHES: A CLUE TO GLOBAL WARMING?

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The large Neptunian satellite Triton is a geologically active body that apparently undergoes complex seasonal changes in its 165 year journey around the sun. Because it is the vehicle for the seasonal transport of volatiles, Triton's atmosphere is expected to undergo large changes in temperature and pressure on a time scale of decades[1]. Evidence for volatile transport has been furnished by changes in Triton's color[2] and a recent observation of global warming on Triton[3]. We obtained a high resolution spectrum of Triton at the 200-inch Hale telescope on Palomar Mountain on October 23, 1997. Triton's color has changed sharply since the last time a spectrum of it was published[2]. Moreover, our spectrum closely matches one obtained in 1977, that appeared to be short-lived[4,5]. These spectral changes may be caused by a short-lived geologic phenomenon, and they would inevitably cause an increase in Triton's temperature. This increase would precipitate the release of additional volatiles and provide the energy required for global warming of Triton. Astronomical observations of Triton provide evidence that short-lived events are important for understanding global climate change on planets.

The large Neptunian moon Triton is one of two satellites in the Solar System that are known to be currently geologically active. At least two geyser-like plumes were observed by the Voyager 2 spacecraft in 1989, and dozens of streaky deposits hint at the existence of many more[6]. Triton also exhibits seasonal changes in its 165 year journey about the sun[1,7,8]. Because Triton's atmosphere serves as the instrument for the transport of volatiles (primarily nitrogen and methane) during this seasonal cycle, its atmospheric pressure may fluctuate by as much as an order of magnitude[9]. Photometric measurements of its albedo and color over a half century suggest that seasonal volatile transport has indeed occurred during that period[2]. There is also evidence that its rotational light curve, which indicates the rough distribution of high albedo volatiles, had changed in the decade between 1981 and 1991[10].

In addition to seasonal changes on Triton, there have also been past indications that more extreme changes - perhaps due to short- lived geologic events - occurred on Triton. Two independent groups reported an anomalously red spectrum for Triton in 1977[4,5]. Because these two observations were obtained in the same year (1977) that other observers noted a more "normal" color for Triton[11,12], these color changes would necessarily have been short-lived. No observation since 1977 has noted a red spectrum for Triton[2,13,14].

We obtained four spectra of Triton between 0.35 and 0.95 μm with the 200-inch Hale telescope and the double spectrograph[15] at Palomar Mountain Observatory on October 23, 1997. The spectral resolution was 10 Angstroms between 0.35 and 0.55 μm and 5 Angstroms between 0.55 and 0.95 μm. The data were analyzed according to standard procedures, including bias-subtraction, flatfielding, and elimination of the solar spectrum with a solar analogue star (16 Cygnus B).

Our reduced spectrum for Triton is shown in Figure 1, with selected previous observations for comparison. The color of Triton is significantly different from that observed during the past two decades. Moreover, our spectrum is similar to those obtained in 1977[4,5]. These previous spectra may be manifestations of earlier short-lived events.

Young *et al.* [3] observed a global temperature increase of nearly 2 K on Triton in November, 1997. We believe our observations and those of Young *et al.* [3] are both manifestations of an active process that occurs on Triton. The following scenario would offer a plausible explanation for both spectral changes and global warming on Triton. A triggering event such as massive venting causes the deposition of dark, red material onto the surface of Triton. The spectrum of the streaks that appear to be plume deposits are indeed darker and redder than Triton as a whole[16], although they are not as red as our spectrum shown in Figure 1. That other units of Triton are even redder than the streak deposits[16] suggests a complex cascade of phenomena that may involve global sublimation as well. The most volatile, fresh, blue nitrogen ice may initially sublimate to expose a lower layer of red photolysized methane ice[17]. The appearance of this layer causes an additional temperature rise. Of the mapped geologic regions on Triton, our spectrum is most similar to that of McEwen's Unit 3, which is probably rich in irradiated methane clathrate[16]. Further, our spectrum shows a more pronounced methane absorption band at $\sim$0.73 μm than recent spectra[13].

Whatever the triggering mechanism(s), Triton's surface will warm significantly as its visual and near UV albedo decrease. The Bond albedo (A = pq, where p is the geometric albedo and q is the phase integral) of Triton is among the highest of any body in the Solar System. Its energy balance is thus particularly sensitive to small variations in its albedo. At the time of the Voyager 2 encounter A was 0.89 in the visual region of the spectrum, where most of the solar flux occurs[6]. Since $T \sim (1\text{-}A)^{1/4}$, where T is the temperature, a change of only $\sim$3% in the Bond albedo would account for the temperature increase observed by Young *et al.*

The spectral change illustrated in Figure 1 could easily account for all of the global warming measured by Young *et al.* [3] Our spectrum shows a 30% change at $\sim$0.44 μm, where the solar flux peaks (we observe little change beyond 0.55 μm; if anything Triton is slightly brighter in this spectral region). Even when one factors in all the possible mitigating factors, such as hemispheric dichotomies, a changing emissivity, and greater limb darkening for bright blue material, the spectral changes we observed provide evidence that global warming on Triton may be due to a short-lived geologic event rather than a seasonal change. It is impossible to know whether Triton warmed during its previous reddening episode in 1977, because the the technology for measuring temperatures on faint distant objects did not exist at that time.

Models for global seasonal change on Triton that include only the effects of solar insolation could underestimate global temperature changes and the atmospheric loading of volatiles.

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Figure 1. The spectral reflectivity of Triton, obtained in October 1997 with theDouble Spectrograph and the 200-inch Hale Telescope at Palomar Mountain Observatory. The spectrum from the Voyager Imaging Science Subsystem (ISS) and Photopolarimeter Subsystem (PPS) are represenative of Triton's color in ~1990. Bell *et al.* 's spectrum was obtained in 1997.

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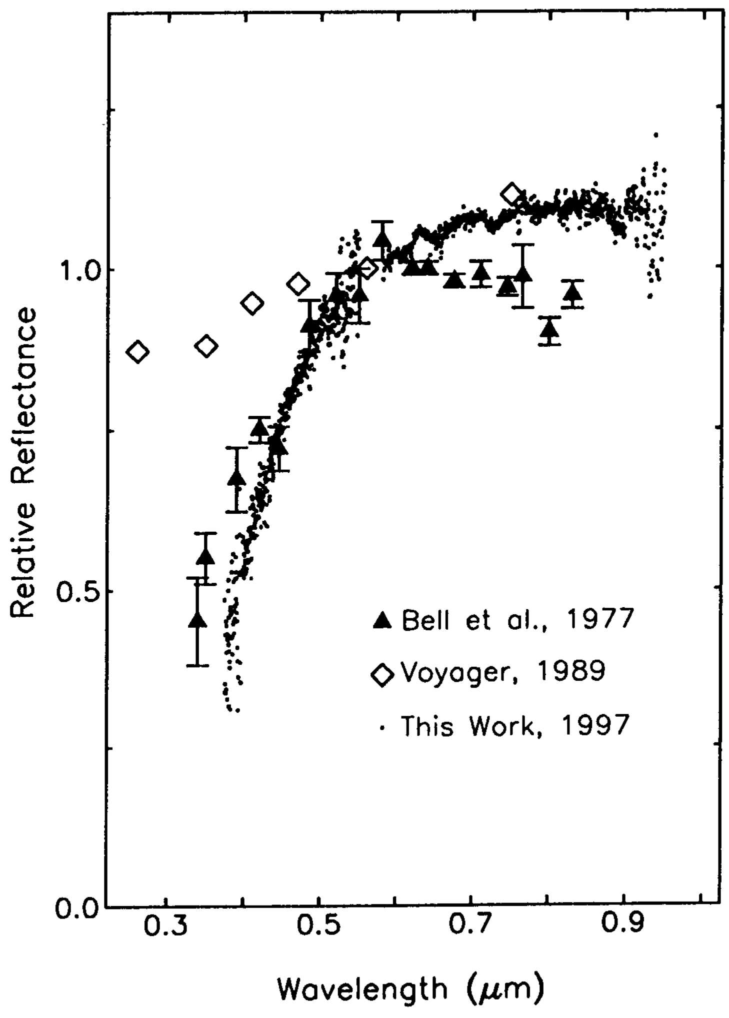
Figure 1:



Relative Reflectance
1.0
0.5
0.0
0.3
0.5
0.7
0.9
Wavelength (μm)
▲ Bell et al., 1977
◇ Voyager, 1989
· This Work, 1997